TYPOLOGIES FOR WALKABLE COVERS OF HISTORIC SITES

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Abstract:
Historic and archaeological sites are often subjected to harmful environmental as well as human factors. Protective structures or shelters do not always result in the desired result, since the authentic character of the site may be impaired. By building walkable covers above the area, social interest in historic remains can be promoted, as visitors can observe them from above without intruding activity or influence the ambient conditions. In addition, these walkways can be equipped with lateral cables to shift foils above the site, whenever visits are prevented by the weather. Three typologies of adapted footbridges are introduced. For each type, requirements of strength, stability, human induced vibration and effects of wind, including vortex are being verified. In some cases vortex shedding seems the most critical condition, albeit simple adequate systems can be installed for mitigation.

Key words: *Footbridge, covering, historic site, structural slenderness, analysis.*

1. Introduction – Covering of historic sites

On one hand, historic sites should be accessible to the broad public, allowing displaying the cultural heritage and thus improving social interest. On the other hand, important remains should be protected from human influence as well as from environmental impact [1]. For this, light covers of various types have been developed. A discussion was raised whether these covers may not be harmful in certain ways, for instance the existence of unwanted shadows, insufficient ventilation or increase of humidity. In addition, the cover may result in harming the authentic character of the site. Preservation and authenticity have gained importance as ICOMOS [2] has set up guidelines and is promoting a shift towards the sustainable long-term approach. However, the focus still is on protection and does not consider any possibility for the public to walk on top of the site. The latter would provide both : allow the public to see remains albeit from a bird's eye position and protect the site from environmental and human impact.

The idea of creating elevated walkways for visitors certainly is not original and has been applied in the Acropolis museum, at a Roman villa in Sicily and recently at the Kipdorp site above 16th century fortifications of the city walls [3].

Hence, this research concentrates on the development of walkable covers and tries to develop those for typical situations. Obviously, each situation may require an individual

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approach. Nevertheless, proposals for typical conditions may inspire particular projects and perhaps result in an alternative way of historic site tourism.

2. Requirements for walkable covers

Obviously, a walkable cover necessarily means to guide the people along a well-defined path. Thus, the cover does not encompass the whole area of the site and needs to be a footbridge. Should the whole area be covered, visitors will be unable to see anything of the remains. There should be no contradiction with the requirement to be able to shelter the whole area, since the footbridge may be equipped with cables running from its edges to the perimeter of the site and foils could be drawing between both. Hence, the cover becomes essentially a footbridge.

According to the code [4], large footbridges should be designed for a vertical load of 2.5 kN/m² and possibly a service vehicle of 80 kN. As the number of visitors should be limited, a vertical load of 1.5 kN/m², which applies to rural walkways, has been considered and the service vehicle has been reduced to 3 kN. Wherever people can assemble, like at a central viewpoint, the design load has been increased to 2.5 kN/m², which corresponds to half of a normal crowd load. People in charge of exploiting the site should carefully oversee the limitation to these conditions, which are a very realistic assumption. In addition to this wind load has to be considered as well as vibrations and comfort conditions for the public.

The horizontal clearance of the footbridge should be at least 2 m, allowing easy passage for visitors, the slope being limited to 1/12 for access by wheelchair users. In addition, larger spaces should be present at preferred locations. Another important requirement is to consider a horizontal load if 1 kN, caused by people leaning on railings, which often occurs on panoramic viewpoints. This load also produces a torque of 1.1 kNm, since the railing should be 1.1 m high.

4. Reference cases

A large survey of the existing archaeological and historic sites was conducted This enabled to distinguish between smaller sites of about 50*50 m and larger sites of 200*200 m. Some of these are more circular whereas others are approximately square. Most sites are at ground level, others having a higher object, like a tower or higher part of the remains. In most cases intermediate supports would absolutely disturb the site. These data have been summarized in Table 1 of the reference cases under consideration.

Table 1. Levels of vibration

Nr	Form	Dimensions	Level	Supports ?
1	Circular	200 m diameter	Remains at ground level	No
2	Square	200 * 200 m	Remains ground level 1 higher	No
3	Square	50*50 m	10 m above ground level	allowed

Obviously, some sites may be underground or be larger than the dimensions of Table 1, and be located below the ground surface. However, the research had to be limited. Aesthetics will be an important requirement, although the structure should not be a monument or eye-catcher itself, since attention of the people should keep concentrated on the remains. Visitors should be able to interpret the site and understand what it stands for. The design has therefore been kept simple and straightforward. Most elements of the footbridges are circular tubes. This is inspired by the fact that tubes provide a dynamic aspect to longer structures and produce soft shade

5. Proposed designs

5.1. Straight passage

This concept would apply to a rather large circular site of 200 m diameter, the site not having any elevated parts. To cover the whole area, a straight arch footbridge is proposed, containing a central wider part for agreeable oversight and panoramic view. Both entrances are also wider and invite visitors to start their tour. The model can be seen in Fig. 1

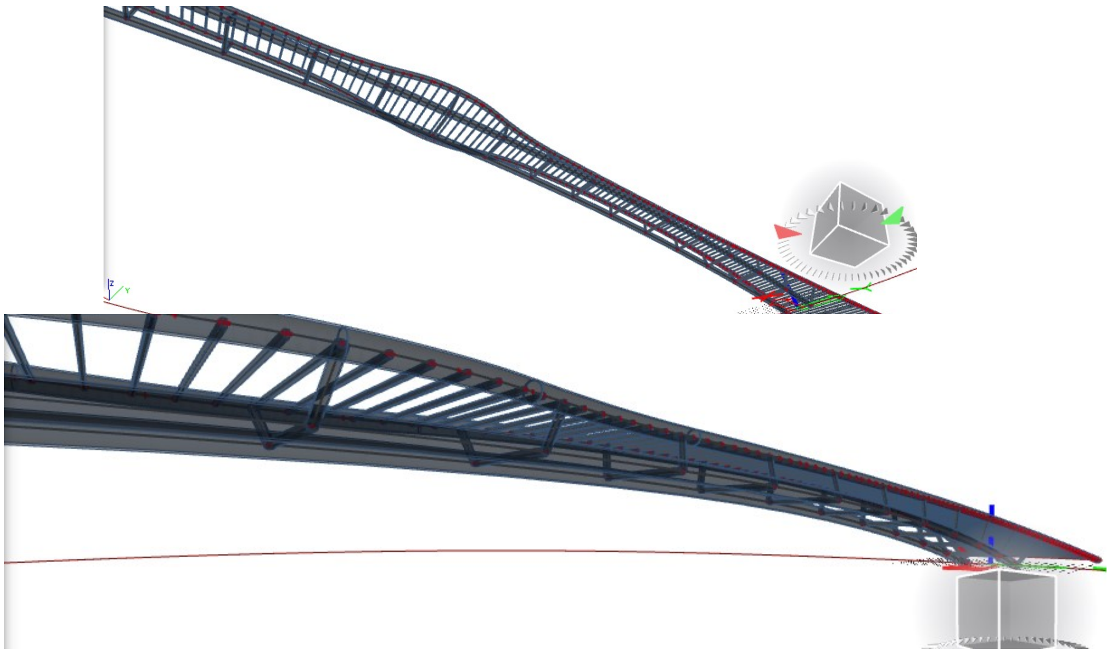

Fig. 1 : Straight passage (top seen from above- bottom seen from below)

The cross-section consists of 2 lateral tubes (1100*80mm) and 2 lower tubes (1300*80mm). The upper tubes show a tendency to buckling, the lowest modes corresponding to a single and 2-wave lateral pattern. The steel grade was increased to S 460 for tackling this problem. The final design shows a unity check of 0.97 and satisfies all requirements.

Concerning the effect of people walking on the footbridge, some natural frequencies are within the critical domain of 1.25 to 2.3 Hz for vertical vibration and 0.50 to 1.20 Hz for lateral movement. Hence, the accelerations have been determined according to [5]. These values should not exceed 0.5 m/s² for vertical – and 0.1 m/s² for horizontal vibration. These requirements certainly are satisfied, since vertical accelerations are limited to 0.0035 m/s² and horizontal ones to 0.0069 m/s². Dynamic effects due to wind are equally excluded, since the critical wind velocity is out of the range of wind, as the Strouhal number equals 0.174. Rain-wind induced vibrations are sheltered, since the Scruton number equals 94, which exceeds the critical lower boundary of 20.

This design is light and allows a complete glass floor for maximum transparency. The arch springs are at ground level, just outside the site and allow limiting the slope of the entrance. It might be considered to include an elevator for wheel chair users in the abutments. The straight passage is a simple structure and does not conflict with more important objects as historic remains.

5.2. Tripod typology

This typology would be adequate to cover a rectangular area that may include a higher object, for instance a tower or series of remaining columns. Two legs of the tripod would surround the freestanding higher object. The structure is more complicated and covers a larger area. The general layout is similar to the straight passage, since wider entrance is provided at each leg and a central viewpoint is located at the highest central area. The 3 legs together constitute an arch, although the transfer of the arch compression force is disturbed due to the angular rotation of the arch branches. Fig. 2 shows views from above and from below of the tripod alternative. The top view, also shows the subjacent site area and the location of the higher object.

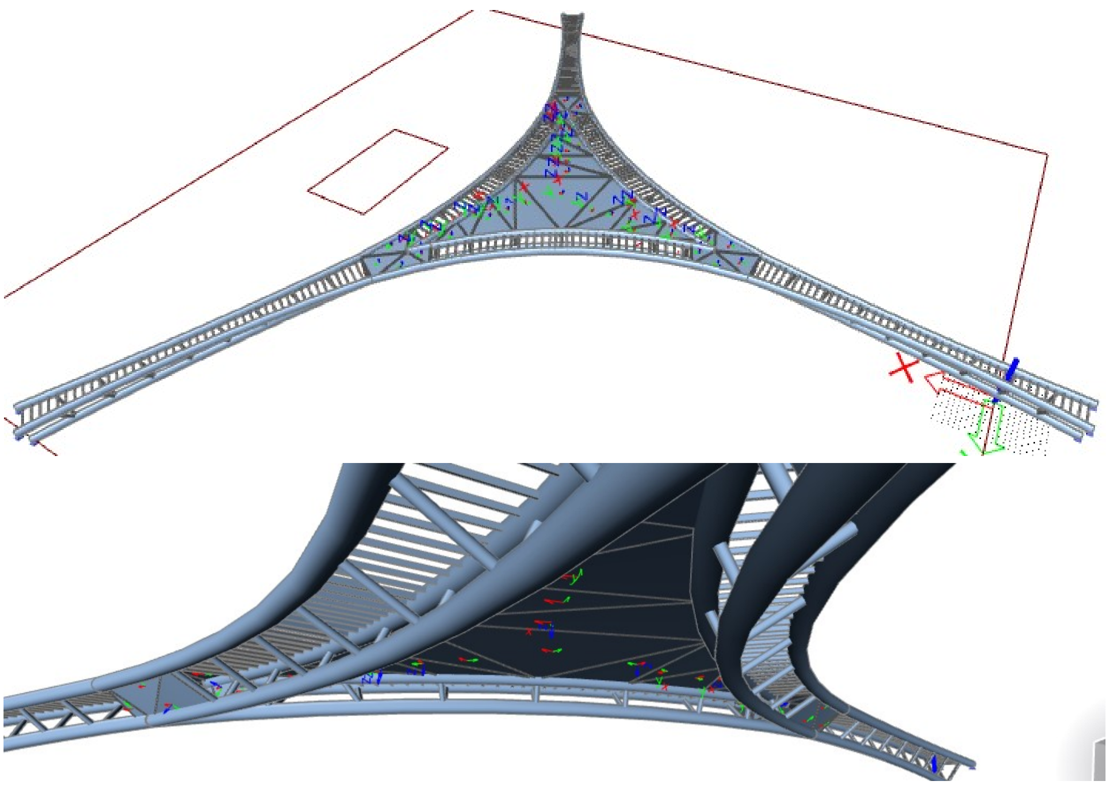

Fig. 2 : Tripod alternative view from above (top) and from below (bottom)

Initially, the objective was to have a circular hole at the centre of the tripod. However, due to the deviation of the thrust force, the ring had to be reinforced heavily and the horizontally curved tubes would be exposed to heavy bending as well as buckling. As a consequence, the central area has to be closed completely with hollow core steel plate. The latter also enables to redistribute compression force from the inside tubular members towards the opposite direction. The lowest stability modes relate to buckling of this connection plate.

The dimensions of the tubes are similar to those of the straight passage and the unity check renders a maximum value of 0.97. As can be expected, the fundamental frequency is higher than for the previous typology and reaches 0.64 Hz for rotational vibration. The acceleration of the structure equals 0.00082 m/s² and is acceptable.

However, the wind loads can have a negative effect on this structure, since the critical wind speed equals 19 m/s² and the Scruton number equals 16.12 Hz. This means that vortex and rain-wind induced vibration is not excluded. Since this vibration is essentially torsional, it may effectively be eliminated by the simple solution of sealed TLCD (sealed tuned liquid column dampers) [6]. The latter is a simple device, which can be fabricated by any constructor and is less costly than tuned mass dampers.

This design is more imposing and eye-catching than the straight passage and prevents the incidence of light at the central area, the glass floor being limited to the three legs of the tripod. Again, the arch springs are at ground level, just outside the site and allow limiting the slope of the entrance. This is a more complex structure and may conflict with more important objects as historic remains, although it allows to approach the elevated object more efficiently.

5.3. Ring

The idea of this typology is to allow elevated view from the perimeter of a smaller site, containing an elevated part and to walk completely around all remains. Visitors are able to physically approach each part to a maximum distance of half the ring diameter. A circular footbridge of approximately 250° is built around the perimeter, both ends being at ground level. This alternative approaches most the existing walkways that may be found in certain museums. Unfortunately, the ring needs to be supported by at least 2 intermediate columns, which have been designed as V-shaped tubular piers. The general layout is seen in Fig. 3.

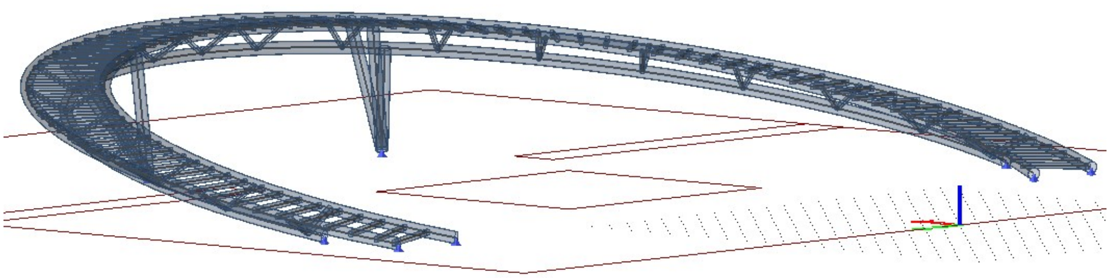

Fig. 3 : general layout of typology Ring

The system of tubes is much lighter than with the previous typologies. The lower tube is limited to CHS 500/12 whereas the upper edge members correspond to CHS 480/12. Obviously, this results from the smaller scale of the structure. In addition, the supports can be of the type CHS 480/10, the thickness being close to the limit for local crippling. Clearly, the largest span sections are subjected to large torsion and the critical buckling modes originate from the combined effect of torsion and bending, as can be seen in Fig. 4.

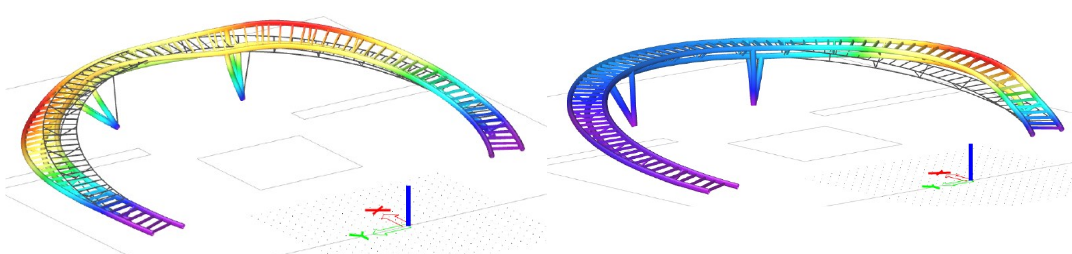

Fig. 4 : Fundamental stability modes of Ring

Since these elements are the lightest, the unity check for the columns is the most critical and reaches 0.99. The lateral edge tubes show a unity check of 0.86. Should a plated connection of the lateral tubes, the lower one and the web tubes be created, the stability modes would certainly render higher critical load, thus seriously improving the buckling load. However, this would decrease the degree of transparency of the tubular structure and its overall quality.

The natural frequencies vary from 1.48 Hz to 6.64 Hz and are at the edge of the critical range. The second vibration mode corresponds to the vertical deformation and results in 0.13 m/s^2 acceleration, which is considerably larger than for the other typologies, due to the lighter mass of the structure. The critical wind speed equals 16.21 m/s and wind may certainly generate vortex and rain-wind induced vibration, since the Scruton number equals 18.9. As the vortex originates from torsional movement, sealed TLCD-dampers can easily prevent this type of vibration.

The alternative without intermediate supports has also been considered. Torsional effect and the cantilevering character of the structure introduce massive, stability problems. The typology becomes unrealistic, since the size of the tubular elements should be tripled at least.

Conclusion

Three typologies of footbridges above reference types of historic sites have been developed. These walkable covers can provide safe and comfortable passage for visitors and provide sufficient visibility of remains, without interfering with the authentic character of the site. Each of these typologies has been verified regarding strength, including stability conditions, human induced vibration, critical wind speed and vortex shedding. For all types, the latter phenomenon seems the most critical, mitigation being provided in an easy manner by equipping the structure with sealed tuned liquid column dampers.

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